11DBMCInternational Conference on Durability of Building Materials and Components

ISTANBUL, TURKEY May 11-14th, 2008

A Model for Determining Accelerated Ageing Cycles in Durability Research: a Case study on Continuous Roofing

Maurizio Nicolella [1]
Alba De Pascale [2]

T 22

ABSTRACT

This paper introduces research about a model for determining the experimental ageing cycle in laboratory tests for evaluating durability. The model has been implemented with computer software that uses an algorithm in which the input is comprised of a series of climatic data that was obtained from various national climatic database sources. The model was implemented specifically for evaluating a continuous roofing sub-system, as part of a broader Italian national research project, related to the durability of building components. The Italian national research project has one that encompassed a network of research organisations from the Universities of Brescia, Catania, Milan, Naples, Palermo and Turin. Research on the durability of continuous roofing has typically been based on a comparison between the results from artificial ageing tests (conducted in a laboratory) with those obtained from natural weathering tests on the same sample. The approach taken in this research project was to attempt to simulate - in the laboratory - the environmental actions that roofing sub-systems are typically exposed to, in relation to the various climatic conditions in which they are expected to perform. The computer output derived from an application of the model provides for the duration of laboratory ageing sub cycles - each one representing, and essentially reproducing a climatic season - with respect to temperature, humidity, sunlight radiation, and rainfall to which the sample is subjected. In this way a "virtual year" is obtained comprising four climatic seasons, each having different values for temperature, humidity, sunlight radiation and rainfall. The values to consider in laboratory tests are those, for the region and the time of year, which represent the season in question. The necessary values for implementing the model proposed are fixed and given in the research for three particular contexts (Milan, Naples and Palermo)

Actually, a method to compose the cycles test in any climatic context for various kinds of experimentation in laboratory about the simulation of environmental effects on each part of building has been already implemented.

KEYWORDS

Accelerating ageing test, environmental effect, re-scaling, artificial ageing test

[1] University of Naples Federico II, D.IN.E., Naples, Italy, Phone +39 081 7682141, Fax +39 081 7682141, maurizio.nicolella@unina.it
[2] University of Naples Federico II, D.IN.E., Naples, Italy, Phone +39 081 7682141, Fax +39 081 7682141, adepasca@unina.it

1 INTRODUCTION

This paper introduces the first part of a study project (part of a national research on the durability of building components) that was conducted and coordinated by Prof. M. Nicolella,. The Naples part of this research concerned the behaviour of roofing subsystems in specific climatic contexts, estimated by comparing laboratory ageing tests with natural weathering tests on similar samples of roof systems. To obtain successful and suitable laboratory tests, and, therefore, a more reliable re-scaling of data, the research group has defined some specific ageing cycles that simulate the appropriate environmental test conditions. Building from that model, the research group has generalized a system defining the method to determine the ageing cycles to apply in the laboratory for the simulation of every specific environmental context. In this paper, we intend to introduce this model and, in so doing, provide a general method to determine the accelerated ageing cycles in durability research. This effort comes from the lack of standardized approaches in defining accelerated ageing tests on building components.

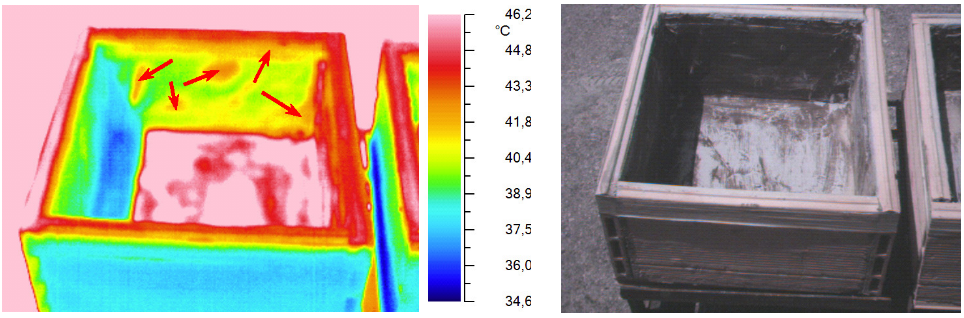

Figure 1. Infrared videothermography inspection on a sample of one of the roofing systems analyzed.

2 IMPORTANCE OF THE STANDARDIZATION OF ACCELERATED AGEING TEST METHODS

Durability standards for building materials and components provide different approaches for estimating service life, but, nevertheless, only generic procedures are given. A general approach is also adopted when determining the service life of components in comparison to results from laboratory ageing with natural weathering tests.

For example, the ASTM E 632-82 - "*Standard Practice for Developing Accelerated Test to Aid Prediction of the Service Life of Building Components and Materials*" –one of the most important references on the matter - does not provide a detailed description of the way in which accelerated, or in-service performance testing, should be carried out.

The accelerated ageing tests advocated in this standard have been carried out by imposing higher than normal stress levels on components in order to increase the rate of degradation such that the component will fail within a relatively short period of time in relation to its expected service life. The performance and failure-time data derived from these tests have been analyzed by fitting a degradation model to the data to estimate the relationship between performance, time to failure (age), and stress level.

Although the theoretical procedure introduced in the standard ASTM is very clear, some important and typical shortcomings about the use of accelerated tests to estimate the service life, include:

- Difficulty simulating the degradation mechanisms of the various materials and their interaction;
- Difficulty reproducing the stochastic nature of the degradation factors affecting the building components;
- Difficulty correlating accelerated laboratory test results with the actual in-service results;
- Difficulty defining suitable accelerated ageing tests to reproduce the effects of specific environmental conditions.

Generally, in National and International standards dealing with ageing test methods, as is the case with this ASTM standard, only a limited series of criteria for determining the environmental conditioning cycle are provided. This, in turn, leaves a certain degree of attitude for defining experimental ageing conditions in the laboratory.

On the contrary, we believe, that the obligation to proceed to a re-scaling should influence the conditioning cycle, which must necessarily be differentiated according to the diverse contexts in which the re-scaling occurs. Otherwise, only comparative tests and studies would be possible, through which we could only determine analogous patterns of behaviour between the different ways in which the same element is used.

In other words, we do not believe to be reliable a re-scaling performed in significantly different climatic contexts, where a sample is subject to the same artificial action.

On this basis, an attempt was made to design an ageing conditioning cycle which provides an accelerated reproduction of what really occurs to different extents, and in different environmental conditions, to which components may be subjected to over their service life.

3 COMPOSITION OF THE AGEING CYCLE FOR A SPECIFIC TEST CONDITION

The starting point in an attempt to standardize a procedure for the definition of accelerated ageing tests on building components was the need to outline a correct cycle within the national study on roofing sub-systems. We tried to simulate a specific context in the laboratory,, the typical environmental conditions of the city of Naples, and later, we tried to extend and generalize the results by designing a cycle which provides an accelerated reproduction of what occurs in different environmental contexts.

This model uses an algorithm in which the input data comprises a series of climatic data which can be obtained from various sources (principally, air force). The output provides the duration of the sub cycles (each one of which represents, and reproduces a climatic season) with the temperatures, humidity, sunlight radiation, and rainfall to which the sample has been subjected.

In this way, we obtain a kind of “virtual year”, comprising the four seasons in succession, with different values for temperature, humidity, sunlight radiation, and rainfall, with the values inserted for the region and time of year that represents the season in question (as shown in Table 1 below):

Table 1.

Sub cycle	*Action*	*Value inserted*
Freezing	Temperature	Absolute minimum
	Humidity	Mean
	Sunlight radiation	-
	Rainfall	-
Hot / Dry	Temperature	Highest among means

	Humidity Sunlight radiation Rainfall	Mean Xenon lamp lights -
Hot / Humid	Temperature Humidity Sunlight radiation Rainfall	Absolute maximum 95% Xenon lamp lights -
Rainy	Temperature Humidity Sunlight radiation Rainfall	Lowest among means Mean - Splash or puddling

Climatic data was collected in advance from various official sources, covering a period no longer than the last 5 years, on account of the extreme variability in recent times.

The values necessary for implementing the proposed model together with related definitions are given in Table 2 below:

Table 2.

Action	*Value inserted*	*Definition*
Rainfall	Number of rainy days in one year	Value obtained from mean annual value
	Intensity of rainfall	Value obtained from mean annual value
Temperature	Absolute minimum	Value obtained from mean absolute minimum value
	Mean minimum	Value obtained from mean monthly value, calculated as daily mean minimum value, taking lowest value into account
	Absolute maximum	Value obtained from mean absolute maximum value
	Mean maximum	Value obtained from monthly mean value, calculated as daily mean maximum value, taking highest value into account
Humidity	Relative humidity	Value obtained from monthly mean for work for each year
Sunlight radiation	Number of sunny days in one year	Value obtained from annual mean value
	Sunlight radiation hourly trend	Value obtained from annual mean values

It is interesting to note that across the different climate zones in Italy there is little difference between the absolute values for many of the environmental actions.

Two examples suffice to illustrate this point:

- Where absolute maximum temperature is concerned, there is no significant difference between Milan and Palermo. What distinguishes the two contexts is the *number* of days per year in which they reach high temperatures;

- The intensity of rainfall recorded in Naples in the last five years exceeds, to a considerable extent, that of Milan in some winter months.

It so happens that for contexts and climates which differ significantly, the seasonal sub cycles determined have (for example) similar temperatures. It is the length of the segment, or the combined effect of the other environmental actions, which characterizes each context.

The final output generated by special simulation software providing the values for Naples are shown in Table 3 below:

Table 3.

Sub cycle Naples	*Dur.*	*Temp.*	*Hum.*	*Sun rad.*	*Rainfall*
Freezing	6 hrs	4 C°	70%	No	No
Hot / Dry	9 hrs	25 C°	60%	Yes	No
Hot / Humid	9 hrs	40 C°	95%	Yes	No
Rainy	6 hrs	10 C°	75%	No	Yes

The values in the Table are provided in Figure 2 below.

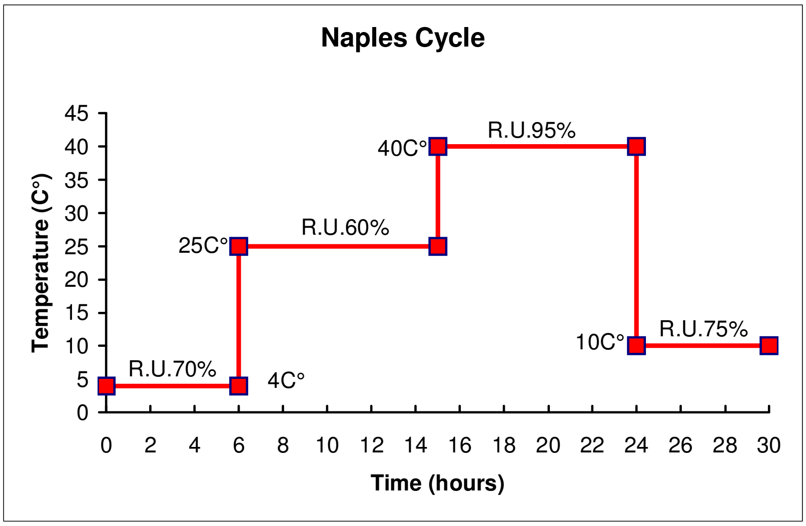

Figure 2. Proposed accelerated ageing conditioning cycle for ageing components in Naples

4 COMPOSITION OF AGEING CYCLE FOR ANY CLIMATIC CONTEXT

By adopting the criteria described, one can develop – as was done for Naples – a simulated cycle for any environment. A schematization has been provided with the options to be exercised by the operator with regard, not only to specifically climatic data (temperature and humidity) but, also, the lamp activation mode in the two heat segments, and, above all, the duration of the various segments in which the sub cycles are contained. Therefore, the process should first be conducted for the individual sub cycles, and then, used as a direct indicator for the selection of climatic data and durations by the user wishing to compile and customize the cycle for the local climatic context.

Note that the length of the segments is not only established in relation to climatic data in terms of temperature and humidity, but is also evaluated, as mentioned above, in terms of the longevity of the season in relation to the annual climate. For example, maximum temperatures recorded in the hottest months in Milan are as much as those in Palermo, regardless of the fact that these two locations belong to climatically diverse contexts. What is important is the duration of elevated temperatures, indeed, and the effect on the climatic trend for the entire year. Such periods of oppressive heat in which temperature peaks occur, can vary significantly from location to location.

To assist in the schematization of this process, the Italian National Zoning Plan (Italian directive 412/93) has been used, based on the number of degree-days[1] recorded for the different districts. This directive provides information on the delineation of Italy into 6 subdivisions [2]. For the present purposes, given the similarities of performance between pairs of subdivisions, they were examined two by two; hence the observed subdivisions include zones A and B, C and D, and E and F , for. By crossing the climatic data (absolute or mean values) with the impact percentage of the reference climatic season for the trend of the climatic year (here illustrated by zones A to F, as determined by the legislation), we will be able to correctly estimate the duration for which the season in question must be schematized in the reference sub cycle.

In light of the above considerations, the following schematizations are proposed:

Sub cycle A – FREEZE: Definition of climate conditions		
Parameter	*Instruction*	*Value*
Temperature	Enter absolute zone minimum value recorded in period of year represented by season in question	X C°
Humidity	Enter zone mean value for season in question	Y %
Sunlight radiation	Keep lamp switched off from now on	---
Rain	Switch off water	---
Climate zone	Establish zone	Zones A/B/C/D/E/F

Sub cycle A – FREEZE: Definition of length of segments	
Climate zone	*Value*
Zones A/B	4 h
Zones C/D	6 h
Zones E/F	9 h

Sub cycle B – HOT / DRY: Definition of climate conditions		
Parameter	*Instruction*	*Value*
Temperature	Enter the absolute zone mean maximum value recorded in the period of the year represented by the season in question	25 C°

[1] The "degree-days" of a designated district are the sum, for all the days in a conventional annual warm period, with the daily positive differences between ambient temperature, conventionally set at 20 degrees centigrade, and the daily mean outdoor temperature; the unit of measurement used is the degree-day (DD).

[2] The italian territory is divided into six climate zones according to their degree-days, regardless of their geographic location:

Zone A: districts with degree-days less than 600; Zone B: districts with degree-days between 600 and 900; Zone C: districts with degree-days between 900 and 1,400; Zone D: districts with degree-days between 1,400 and 2,100; Zone E: districts with degree-days between 2,100 and 3,000; Zone F: districts with degree-days greater than 3.000.

Humidity	Enter the zone mean value for the season in question	Y %
Sunlight radiation	Light lamp for zones A/B/C	Maximum value
Rain	Switch off water	---
Climate zone	Establish zone	Zones A/B/C/D/E/F

Sub cycle B – HOT / DRY: Definition of length of segments	
Climate zone	*Value*
Zones A/B/C	9 hrs
Zone D	6 hrs
Zones E/F	4 hrs

Sub cycle C – HOT / HUMID: Definition of climate conditions		
Parameter	*Instruction*	*Value*
Temperature	Enter the absolute zone maximum value recorded in the period of the year represented by the season in question	X C°
Humidity	Enter a fixed value	95 %
Sunlight radiation	Keep lamp switched on always	Maximum value
Rain	Switch off water	---
Climate zone	Establish zone	Zones A/B/C/D/E/F

Sub cycle C – HOT / HUMID: Definition of length of segments	
Climate zone	*Value*
Zones A/B/C	9 hrs
Zone D	6 hrs
Zones E/F	4 hrs

Sub cycle D - RAIN: Definition of climate conditions		
Parameter	*Instruction*	*Value*
Temperature	Enter the mean zone minimum value recorded in the period of the year represented by the season in question	X C°
Humidity	Enter the zone mean value for the season in question	Y %
Sunlight radiation	Keep lamp switched off from now on	---
Rain	Water	30 mm of water
Climate zone	Establish zone	Zones A/B/C/D/E/F

Sub cycle D - RAIN: Definition of length of segments

Rainfall band	*Value*
Band 1: less than 50 days/year	4 hrs
Band 2: 50 – 90 days/year	6 hrs
Band 3: over 90 days/year	9 hrs

From these results, we have also developed specific software to automatically compose the seasonal sub-cycles using the criteria introduced above. An image of this software is provided in Figure 3.

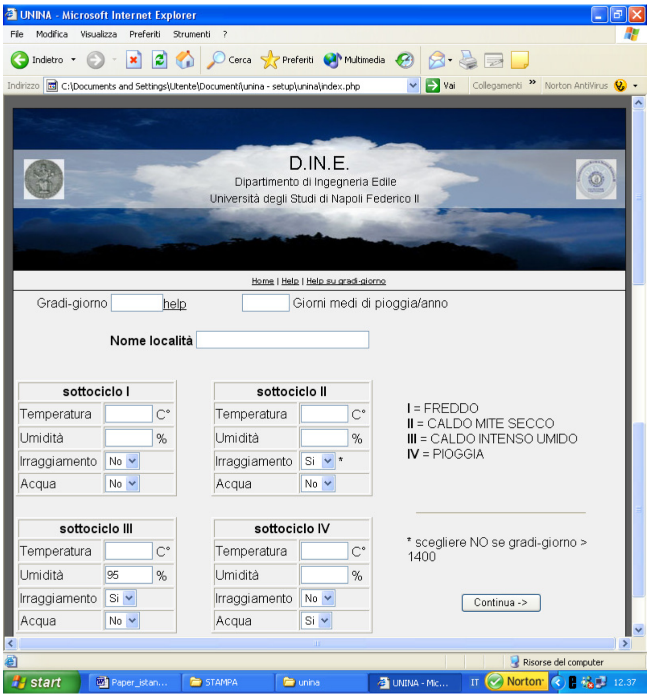

Figure 3. A screen from the software for the automatic composition of accelerated ageing sub-cycles in any climatic context.

5 REFERENCES

ASTM E 632-82, *Standard Practice for Developing Accelerated Test to Aid Prediction of the Service Life of Building Components and Materials*

BS 7543, *Guide to durability of buildings and building elements, products and components*, BSI, London

ISO 6241, *Performance standards in building – Principles for their preparation and factors to be considered*, ISO, Geneva

ISO 15686, *Buildings and constructed assets — Service life planning - Part 1: General principles,* Geneva

ISO 15686, *Buildings and constructed assets — Service life planning - Part 2: Service life prediction procedures*, Geneva

UNI 11156, *Valutazione della durabilità dei componenti edilizi – Part. 1,2,3*, UNI, Milano

Maggi, P.N. 2003, *Qualità tecnologica dei componenti edilizi: la durabilità*, Epitesto, Milano

Maggi, P.N. 2003, *Qualità tecnologica dei componenti edilizi: la valutazione della durabilità*, Epitesto, Milano

De Pascale, A. Nicolella, M. 2005, *Service life of building components. Analysis and proposals of definition of the modifying factors,* in Atti del 10th International Conference on *Durability of Building Materials and Components,* Lyon (France)

De Pascale, A. 2003, *Modifying factors in a method for estimating service life* in Atti del *Management of durability in the Building process*, Milano 25-26 Giugno

De Pascale, A. 2002, *Modifying factors of a method for estimating service life* in Atti del 9th International Conference on *Durability of Building Materials and Components,* Brisbane Convention & Exhibition Centre, Queensland (Australia)

De Pascale, A. 2000, *Determinazione sperimentale del ciclo di vita utile di elementi costruttivi ai fine della programmazione di interventi di manutenzione*, Tesi di dottorato in "Tecnologie per il recupero edilizio e l'innovazione tecnologica", D.IN.E., Napoli

Jernberg, Sjöström, Lacasse, Brandt, Siemes, 2004, *Guide and Bibliography to Service Life and Durability Research for Buildings and Components*, Joint CIB W080 / RILEM TC 140, CIB Publication, Rotterdam

Lounis, Z., Lacasse, M.A., Vanier, D.J., and Kyle, B.R., *Towards Standardization of Service Life Prediction of Roofing Membranes*, Roofing Research and Standards Development: 4th. Volume, ASTM STP 1349, T. J. Wallace and W.J. Rossiter, Jr., Eds., American Society for Testing and Materials, 1998.

Nicolella, M. 2006, *La durabilità delle coperture continue*, Ediltecnica srl, Palermo

Nicolella, M. 2004, *Programmazione degli interventi in edilizia*, UNI, Milano

Nicolella, M. 2003, *A methodological hypothesis for estimating service life*, in Atti del Convegno Internazionale *Management of durability in the Building process*, Milano 25-26 Giugno

Nicolella, M. 2002, *Components service life: from field test to methodological hypothesis*, in Atti del 9th International Conference on *Durability of Building Materials and Components,* Brisbane Convention & Exhibition Centre, Queensland (Australia)

Nicolella, M. 1997, *Valutazione semiprobabilistica del comportamento in servizio de elementi costruttivi per la determinazione dell'affidabilità*, Tesi di dottorato in "Tecnologie per il recupero edilizio e l'innovazione tecnologica", Dipartimento di Ingegneria Edile, Napoli

Nicolella, M. 2000, *Affidabilità e durabilità degli elementi costruttivi in edilizia*, CUEN, Napoli